An Alternative Approach to Aerosol Model Selection in the SeaWiFS Atmospheric Correction Algorithm

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I. Introduction

The standard SeaWiFS atmospheric correction algorithm of Gordon and Wang derives the aerosol radiance at each wavelength by interpolation between two aerosol models. The model selection is based on comparisons between the single scattering aerosol reflectance ratio, ε, for each model and a predicted ε value, where the predicted value is also derived using model relationships to translate the measured multi-scattering aerosol reflectances in the NIR to single scattering aerosol reflectances. Although the approach works well in simulation and seems to work well in practice, it requires a series of iterations to reduce the number of potential models from twelve to two. This document describes an alternative approach that seems to yield very similar results, but which does not require any iteration.

II. Algorithm Description

For each aerosol model, m, the Gordon and Wang algorithm provides geometry-dependent tables of the single-scattering aerosol reflectance ratio at all SeaWiFS wavelengths, $e_m(\lambda)$. Each model is further characterized by a set of functions which relate single-scattering aerosol reflectances to multiple-scattering aerosol reflectances, $f_m(\lambda)$. These relationships can be written as

$$e_m(\lambda) = \frac{[r_{as}(\lambda)]_m}{[r_{as}(865)]_m} \tag{1}$$

and

$$f_m(l) = \frac{[r_{as}(l)]_m}{[r_a(l) + r_{ra}(l)]_m}, \quad (2)$$

where $[r_{as}(l)]_m$ is the single-scattering aerosol reflectance for model m at wavelength l, $r_a(l)$ is the reflectance resulting from multiple scattering by aerosols in the absence of air molecules, and $r_{ra}(l)$ is the contribution to path reflectance associated with multiple interactions between molecules and aerosols. By ignoring the contributions from sun glitter and whitecaps, the sensor measured reflectance at the top of the ocean-atmosphere system, $r_t(l)$, can be written as

$$r_t(l) = r_r(l) + r_a(l) + r_{ra}(l) + t(l) r_w(l), \quad (3)$$

where $r_r(l)$ is the reflectance resulting from multiple scattering by air molecules in the absence of aerosols, $t(l)$ is the atmospheric diffuse transmittance that accounts for the effects of propagating water-leaving reflectances from the sea surface to the top of the atmosphere, and $r_w(l)$ is the water-leaving reflectance. In general, $r_r(l)$ is known, and in the near infrared (NIR) wavelength regime (670 to 865nm for SeaWiFS) the water-leaving reflectance can be predicted or assumed negligible. Thus, in the NIR channels, Equation 3 can be rewritten as

$$r_a(l) + r_{ra}(l) = r_t(l) - r_r(l), \quad (4)$$

indicating that the aerosol contribution at these wavelengths can be determined directly from the sensor measured reflectance and the known contribution from molecular scattering. The challenge is to extrapolate this knowledge of the aerosol contribution in the NIR to derive the aerosol contribution in the visible bands, and for this the Gordon and Wang algorithm uses models.

For each aerosol model, it is possible to estimate the single scattering aerosol reflectance at 865nm, $[r_{as}(865)]_m$, by application of Equation 2 to the measured aerosol reflectance. i.e.,

$$[r_{as}(865)]_m = [r_a(865) + r_{ra}(865)]\, f_m(865) \quad (5)$$

From this model-specific estimate of $[r_{as}(l)]_m$ and equation 1, it is then possible to compute $[r_{as}(l)]_m$ at all remaining wavelengths as

$$[r_{as}(l)]_m = e_m(l)\,[r_{as}(865)]_m . \quad (6)$$

And finally, by applying Equation 2 again, it is possible to derive model-specific estimates of the multi-scattering aerosol reflectance at all remaining wavelengths. i.e.,

$$[r_a(l) + r_{ra}(l)]_m = \frac{[r_{as}(l)]_m}{f_m(l)} \quad (7)$$

Equations 5 through 7 show that it is possible to predict the multi-scattering aerosol reflectance that would result for various candidate atmospheres, given a measurement of aerosol reflectance at 865nm.

The standard Gordon and Wang algorithm performs this exact series of calculations, but Equation 7 is only applied to the visible bands, and only for the two selected models. The two models are determined by relating the model values of $e_m(l)$ with predicted values, $[e_m(765)]_p$, as derived by application of Equation 2 to the measured aerosol reflectances in two NIR channels. e.g.,

$$[r_{as}(865)]_m = [r_a(865) + r_{ra}(865)]\, f_m(865)$$

$$[r_{as}(765)]_m = [r_a(765) + r_{ra}(765)]\, f_m(765) \quad (8)$$

$$[e_m(765)]_p = [r_{as}(765)]_m / [r_{as}(865)]_m$$

The Gordon and Wang algorithm currently uses twelve models, so the result of Equations 8 is twelve values of $[e_m(765)]_p$ to be compared with twelve model values of $e_m(765)$. Note that this is in essence a model-to-model comparison. If one of the models did provide a true representation of the atmosphere, then the spectral variation in the measured aerosol reflectance would be exactly as predicted by the model, and $[e_m(765)]_p$ would exactly match $e_m(765)$ for that model. In practice, the algorithm uses an average

of the predicted $[e_m(765)]_p$ values, $<[e_m(765)]_p>$, as an estimate of the "true" value, and it is the comparison between the twelve model $e_m(765)$ values and that average which defines the two selected models and the mixing ratio. Clearly, $<[e_m(765)]_p>$ is dependent on the distribution of the models. To combat this problem, the algorithm was extended to include a series of iterations in which the average is weighted by the differences between each model epsilon and the current $<[e_m(765)]_p>$, the two models with the largest differences are eliminated, and the average is recomputed until only four models remain. Thus, the final two models and the mixing ratio are selected by comparing the weighted average of $[e_m(765)]_p$ over four models with the model $e_m(765)$ values.

Two observations can be made with regard to the above discussion. One is that this selection process seems rather complicated, and a simpler approach will be presented as an alternative. The other observation is that, if the above statements are correct, it seems that the "best" model is simply the one for which the difference between the model $e_m(765)$ value and the predicted $[e_m(765)]_p$ value is minimized. This leads to the suggestion by Wayne Robinson that the final model can be computed as a weighted average, using these $[e_m(765)]_p - e_m(765)$ differences to form the weights for each model.

Whether the final model is derived from interpolation between two bounding models or weighting between three or more neighboring models, the previous discussions assume that the model selection and weighting must be determined in $e_m(l)$ space. In the end, this weighting relationship is applied to the model predictions of $[r_a(l) + r_{ra}(l)]_m$. The suggestion made here is that the weighting relationship can be derived in the same $[r_a(l) + r_{ra}(l)]_m$ space in which it will be applied. As shown in Equations 5 through 7, the Gordon and Wang algorithm already provides the ability to predict $[r_a(l) + r_{ra}(l)]_m$ for a series of candidate atmospheres, using only the measured aerosol reflectance at 865nm as input. This includes predictions for multi-scattering aerosol reflectance at 670 and 765nm, where SeaWiFS also has measurements of the aerosol reflectance. The correct model should be the one for which the difference between the model predicted

$[r_a(l) + r_{ra}(l)]_m$ and the measurement at 765 and/or 670nm is minimized. As in $e_m(l)$ space, it is possible to select two bracketing models and an interpolation ratio, or use the aerosol reflectance differences to derive weights for all twelve models.

With regard to weighting versus interpolation, the weighting scheme suggested by Wayne Robinson is much less likely to produce discontinuities in the aerosol reflectances which can arise in the two-model interpolation scheme, when one model is suddenly dropped in favor of another. The discontinuity arises because, although the two models involved in the transition are nearly identical in the NIR, they can differ significantly in the visible regime, thus causing a discrete shift in the interpolated aerosol reflectance at the shorter wavelengths. All else being equal, such model transitions will occur along lines of constant scattering angle, thus causing systematic artifacts in the retrieved aerosol reflectances and water-leaving radiances. In contrast, the weighting scheme would allow the two models to influence the final solution equally at the transition point, as they smoothly trade for dominance.

Another advantage of the weighting scheme is the ease with which additional information can be incorporated into the weighting function. For instance, it would be fairly simple to define a weighting function which makes use of the model-to-measurement differences at both the 670 and 765nm channels simultaneously, to make better use of the spectral information available.

What follows is one suggestion for a weighting scheme based on the differences between the model predicted $[r_a(l) + r_{ra}(l)]_m$ and the aerosol measurement at 765nm. As also suggested by Wayne Robinson, this approach makes use of a Gaussian functional form for the weights. The width of the Gaussian is chosen to be 1% of the measured reflectance at 765nm, which provides for a rapid decrease in the influence of models which differ significantly from the measured aerosol reflectance at 765nm. This weighting scheme can be written as:

$$\Delta_m = [r_a(765) + r_{ra}(765)]_m - [r_a(765) + r_{ra}(765)]$$

$$s_m = 0.01\,[r_a(765) + r_{ra}(765)]$$

$$W_m = e^{-(\Delta_m / s_m)^2}$$

$$[r_a(l) + r_{ra}(l)] = \frac{\sum_m W_m [r_a(l) + r_{ra}(l)]_m}{\sum_m W_m}$$

This method has been applied to one SeaWiFS scene, where it was found to yield similar results to the standard Gordon and Wang algorithm, but with the exception that it did not reproduce some model-transition artifacts. Clearly, much additional study is necessary before such a change in approach can be considered for operational processing. However, it should also be considered that the proposed algorithm is not altogether different from the current standard algorithm, so the established track-record is still applicable. The suggestion made here is only to simplify the modeling process by looking at predictions of multi-scattering aerosol reflectance rather than $e_m(NIR)$, and perhaps to minimize potential discontinuities through the use of a model weighting scheme rather than discrete model selection.